

CLAIMS

- 1 1. A magnetic field sensor for sensing an applied magnetic field, the sensor
2 comprising:
3 a layer of magnetostrictive material having a magnetization vector that
4 responds to the applied magnetic field by rotating in a plane and generating a
5 stress;
6 a layer of electroactive material, mechanically bonded to the layer of
7 magnetostrictive material, that responds to the stress by generating a voltage; and
8 electrodes that measure the voltage generated by the electroactive
9 material in a direction substantially parallel to the plane in which the magnetization
10 vector rotates.
- 1 2. The sensor of claim 1 wherein the magnetostrictive material is selected from the
2 group consisting of amorphous-FeBSi, FeCoBSi alloys, polycrystalline nickel,
3 iron-nickel alloys, iron-cobalt alloys and Terfenol-D[®].
- 1 3. The sensor of claim 2 wherein the magnetostrictive material is selected from the
2 group consisting of $\text{Fe}_x\text{B}_y\text{Si}_{1-x-y}$, where $70 < x < 86$ at%, $2 < y < 20$, and $0 < z = 1 -$
3 $x - y < 8$ at%, $\text{Fe}_x\text{Co}_y\text{B}_z\text{Si}_{1-x-y-z}$ where $70 < x + y < 86$ at% and y is between 1 and 46
4 at%, $2 < z < 18$, and $0 < 1 - x - y - z < 16$ at%, polycrystalline nickel, iron-nickel alloys
5 where Ni is between 40 and 70 at%, iron-cobalt alloys where Co between 30 and
6 80%, and Terfenol-D[®] $\text{Fe}_2(\text{Dy}_{0.67}\text{Tb}_{0.33})$.
- 1 4. The sensor of claim 2 wherein the magnetostrictive material comprises a
2 composition near $\text{Fe}_{78}\text{B}_{20}\text{Si}_2$.
- 1 5. The sensor of claim 2 wherein the magnetostrictive material comprises a
2 composition near $\text{Fe}_{68}\text{Co}_{10}\text{B}_{18}\text{Si}_4$.

- 1 6. The sensor of claim 2 wherein the magnetostrictive material comprises an iron-
2 nickel alloy with substantially 50% Ni.
- 1 7. The sensor of claim 2 wherein the magnetostrictive material comprises an iron-
2 cobalt alloy with substantially 55% Co.
- 1 8. The sensor of claim 1 wherein the electroactive material is selected from the
2 group consisting of lead zirconate titanate ceramics ($\text{Pb}(\text{Zr}_x\text{Ti}_{1-x})\text{O}_3$),
3 polyvinylidene difluoride polarized polymers (PVDF), aluminum nitride (AlN),
4 quartz (SiO_x), ferroelectric materials, electrostrictive materials and relaxor
5 ferroelectric materials.
- 1 9. The sensor of claim 8 wherein the electroactive material is electrostrictive
2 material substantial of the form $(\text{Bi}_{0.5}\text{Na}_{0.5})_{1-x}\text{Ba}_x\text{Zr}_y\text{Ti}_{1-y}\text{O}_3$.
- 1 10. The sensor of claim 8 wherein the electroactive material is a relaxor ferroelectric
2 material substantially of the form $\text{Pb}(\text{Mg}_{1/3}\text{Nb}_{2/3})_3\text{O}_3$.
- 1 11. The sensor of claim 1 wherein the magnetostrictive layer is bonded to the
2 electroactive layer with non-conductive glue.
- 1 12. The sensor of claim 11 wherein the glue is non-conductive epoxy.
- 1 13. The sensor of claim 1 wherein the electroactive layer is a rectangular prism
2 having thickness, t , width, w , and length, l , with $t \leq w \leq l$ and three pairs of
3 opposing faces and wherein the electrodes are on one pair of opposing faces

- 4 and the magnetostrictive layer and a second magnetostrictive layer are bonded
5 to another pair of opposing faces.
- 1 14. The sensor of claim 13 wherein a third and a fourth magnetostrictive layers are
2 bonded to the third pair of opposing faces.
- 1 15. The sensor of claim 14 wherein the magnetostrictive layer is a continuous piece
2 wrapped around and bonded to two pairs of opposing sides and the electrodes
3 are on a third pair of opposing sides.
- 1 16. The sensor of claim 1 wherein the magnetostrictive layer is disk-shaped
- 1 17. The sensor of claim 1, wherein the electroactive layer is a cylinder with two
2 circular faces and a side wall, the magnetostrictive layer is bonded to at least one
3 circular face and electrodes are on the side wall in an opposing relationship.
- 1 18. The sensor of claim 17 wherein the side wall has a circumference and wherein
2 the electrodes are arc-shaped, each electrode having an arc length of at least $1/8$
3 and not greater than $3/8$ of the circumference of the side wall.
- 1 19. The sensor of claim 1 wherein the electroactive layer is a cylinder of thickness, t ,
2 and diameter, d , and wherein $t \geq d$.
- 1 20. The sensor of claim 1 wherein the electroactive layer is a cylinder with two
2 circular faces of diameter d and a side wall of height h wherein $h \geq d$ and wherein
3 the electrodes are on the circular faces and the magnetostrictive layer is bonded
4 to the side wall.

- 1 21. The sensor of claim 1, wherein the electroactive layer forms a hollow cylinder of
2 length l , thickness t , and diameter, d where $t < d/2$ and $t \leq l$ and a pair of
3 opposing end faces.
- 1 22. The sensor of claim 21 wherein the electrodes are applied to an inner cylinder
2 surface and an outer cylinder surface.
- 1 23. The sensor of claim 22 wherein the magnetostrictive layer comprises a cylinder
2 of magnetostrictive material inserted into the hollow cylinder of electroactive
3 material.
- 1 24. The sensor of claim 21 wherein the electrodes are applied to the opposing end
2 faces.
- 1 25. The sensor of claim 21 wherein the magnetostrictive material layer comprises a
2 single piece of magnetostrictive material wrapped over, and bonded to, an outer
3 surface of the cylinder.
- 1 26. The sensor of claim 21 wherein the magnetostrictive material layer comprises a
2 single piece of magnetostrictive material wrapped over, and bonded to, an inner
3 surface of the cylinder.
- 1 27. A magnetic field sensor for sensing an external magnetic field, the sensor
2 comprising:
3 a layer of magnetostrictive material having a magnetization vector that
4 responds to the applied magnetic field by rotating in a plane and generating a
5 stress;
6 a layer of electroactive material mechanically bonded to the layer of
7 magnetostrictive material that responds to the stress by generating a voltage; and

8 means for measuring the voltage generated by the electroactive material
9 in a direction substantially parallel to the plane in which the magnetization vector
10 rotates.

1 28. The sensor of claim 27 wherein the electroactive layer is a rectangular prism
2 having thickness, t , width, w , and length, l , with $t \leq w \leq l$ and three pairs of
3 opposing faces and wherein the electrodes are on one pair of opposing faces
4 and the magnetostrictive layer and a second magnetostrictive layer are bonded
5 to another pair of opposing faces.

1 29. The sensor of claim 27 wherein the magnetostrictive layer forms a hollow
2 cylinder with an axis and a surface and the magnetostrictive layer has a
3 magnetization vector that changes orientation from circumferential to axial on the
4 surface of the cylinder in response to an external magnetic field applied in a
5 direction parallel to the axis.

1 30. The sensor of claim 27 wherein the electroactive layer forms a hollow cylinder
2 with an axis and a surface and wherein the magnetostrictive layer is wrapped
3 around and bonded to the surface and has a magnetization vector that changes
4 orientation from circumferential to axial on the surface of the cylinder in response
5 to an external magnetic field applied in a direction parallel to the axis.

1 31. The sensor of claim 30 further comprising a second magnetostrictive layer
2 bonded to an inner surface of the hollow cylinder, wherein the second
3 magnetostrictive layer has a magnetization vector that changes orientation from
4 circumferential to axial on the surface of the cylinder in response to an external
5 magnetic field applied in a direction parallel to the axis.

- 1 32. A method for fabricating a magnetic field sensor for sensing an applied magnetic
2 field, the method comprising:
- 3 (a) forming a layer of magnetostrictive material having a magnetization vector
4 that responds to the applied magnetic field by rotating in a plane and
5 generating a stress;
- 6 (b) forming a layer of electroactive material with electrodes that measure the
7 voltage generated by the electroactive material;
- 8 (c) mechanically bonding the layer of magnetostrictive material to the layer of
9 electroactive material so that the electroactive material responds to the
10 stress by generating a voltage and the voltage generated by the
11 electroactive material is measured in a direction substantially parallel to
12 the plane in which the magnetization vector rotates.
- 1 33. The method of claim 32 wherein step (a) comprises:
- 2 (a1) heat treating the magnetic material in the absence of an external magnetic
3 field to relieve stress.
- 1 34. The method of claim 32 wherein step (a) comprises:
- 2 (a1) heat treating the magnetic material in the presence of an external
3 magnetic field to relieve stress and to induce a preferred direction of
4 quiescent magnetization after heat treatment.
- 1 35. The method of claim 32 wherein step (b) comprises:
- 2 (b1) applying a saturating electrical voltage to electrodes in order to polarize
3 the electroactive material.
- 1 36. The method of claim 32 further comprising:
- 2 (d) applying a saturating voltage to the electrodes in order to polarize the
3 electroactive material

- 1 37. The method of claim 32 further comprising:
2 (d) heat treating the sensor to relieve stress in the magnetic material.
- 1 38. The method of claim 37 wherein step (d) comprises
2 (d1) applying a magnetic field during the heat treatment to induce a preferred
3 quiescent magnetization direction.
- 1 39. The method of claim 32 wherein step (a) comprises selecting the
2 magnetostrictive material from the group consisting of amorphous FeBSi, nickel,
3 iron-nickel alloys, iron-cobalt alloys and Terfenol-D®.
- 1 40. The method of claim 32 wherein step (b) comprises selecting the electroactive
2 material from the group consisting of lead zirconate titanate ceramics,
3 polyvinylidene fluoride polarized polymers, aluminum nitride, quartz SiO_x,
4 ferroelectric materials, electrostrictive materials and relaxor ferroelectric
5 materials.
- 1 41. The method of claim 32 wherein step (c) comprises bonding the magnetostrictive
2 layer to the electroactive layer with glue.
- 1 42. The method of claim 41 wherein the glue is a non-conductive epoxy.